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THROAT SLOTS ON THE INTERNAL PERFORMANCE
OF A SIDE INLET AT MACH NUMBERS
OF 2.0 AND 2.3

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SUMMARY

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A wind-tunnel investigation was conducted to determine the effects of varying the boundary-layer-control throat bleed slot width and mass-flow rate on the internal performance of a double-ramp external compression side inlet with a rapid turn. The tests were conducted at Mach numbers 2.0 and 2.3, and at Reynolds numbers from 2.2 to 2.4×10^6 per foot.

Increasing the bleed slot area from 13 to 52 percent of the inlet area while maintaining an approximately constant bleed mass-flow rate resulted in a decrease in inlet maximum pressure recovery with a concomitant increase in distortion. Increasing the bleed mass-flow rate while maintaining a constant boundary-layer-control bleed slot size resulted in an increase in inlet maximum pressure recovery and a decrease in distortion. Comparison of the performance of the inlet with the different bleed slot sizes at their best bleed flow rates showed only minor variations in pressure recovery and distortion; but significant changes occurred in critical mass-flow ratio as a result of the higher bleed flow rates through the larger slots. The inlet experienced larger performance losses at a Mach number of 2.3 than at 2.0 because of variations in both the bleed mass-flow ratio and slot width.

INTRODUCTION

Because of the interest in the field of boundary-layer control for air-induction systems, an investigation was conducted to determine the effect of varying a throat bleed slot size and mass-flow ratio of a boundary-layer-control system for an external compression inlet which incorporates rapid turning of the internal flow. The advantage of using a more rapid turn at the throat of an external compression inlet was

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demonstrated in reference 1. It was shown that a significant reduction in the cowl drag of a symmetrical inlet could be realized with only a small penalty in pressure recovery. Furthermore, in reference 2 it was shown that the use of boundary-layer bleed at the inlet throat in conjunction with the rapid turning of the internal flow resulted in a large improvement in pressure recovery. A survey of available literature revealed that there were insufficient data to design a boundary-layer bleed throat slot for inlets of unlike geometry. Also, it was noted from the survey that there is no standard parameter for specifying the slot width or area. The slot areas were found to vary from 8 to 74 percent of the inlet areas with bleed flow rates varying from 3 to 7 percent of the inlet mass-flow ratio (refs. 2 to 9). Therefore, to determine the best boundary-layer-bleed slot width and mass-flow rate for an external compression inlet which incorporates rapid turning of the internal flow, it was necessary to conduct an experimental investigation. The boundary-layer-control slot was tested in three widths which corresponded to areas of 13, 26, and 52 percent of the inlet area, and the bleed mass-flow rate was varied from 1.0 to 11.5 percent of the inlet mass-flow ratio. The effects of slot width and bleed mass-flow rate on the inlet internal performance, namely pressure recovery, distortion, and compressor-face pressure distribution, were investigated and the results have been presented herein. No drag measurements were made during this investigation.

The present investigation was performed in the 9- by 7-foot test section of the Ames Unitary Plan Wind Tunnel at Mach numbers of 2.0 and 2.3 and an inlet to free-stream angle of attack of $+1^\circ$. Reynolds number of the test varied from 2.2 to 2.4 million per foot.

SYMBOLS

a_1	inlet area perpendicular to second ramp at cowl lip, 7.10 sq in.
a_s	area of throat slot, sq in.
$F_{1,2,3}$	bleed flow control valve positions (control valve opening areas equal to 0.13, 0.26, and 0.52 a_1 , respectively)
$\frac{m_2}{m_\infty}$	main duct mass-flow ratio
$\frac{m_3}{m_\infty}$	bleed duct mass-flow ratio
M	Mach number

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$\frac{p_{t2}}{p_{t\infty}}$ total-pressure recovery

b.l.c. boundary-layer control

Subscripts

av average

max maximum

min minimum

t total

∞ free stream

2 compressor station, model station 40.50

3 bleed duct rake station

APPARATUS AND PROCEDURE

Schematic drawings are presented in figures 1(a), (b), and (c) of the over-all model which consisted of a fuselage forebody with external compression side inlets.

The side inlet consisted of two external compression ramps of near optimum design, 10° and 24° , for a design Mach number of 2.3. The second, or 24° ramp, provided for boundary-layer removal by means of a 0.02-inch gap at the leading edge and a perforated surface as shown in detail C of figure 1. At the inlet throat a transverse slot was used to bleed off the boundary layer through a duct to an exit vent behind the model canopy. The slot widths of 0.13, 0.26, and 0.52 inch were equal to 13, 26, and 52 percent of the inlet area, respectively. The air flow through the throat slot was regulated by a flap valve as shown in figure 1(c). Both the second ramp bleed and the throat slot bleed were exhausted through a common duct.

The area expansion of the inlet subsonic diffuser behind the boundary-layer-control slot was equivalent to that of a 13° included angle cone as shown in figure 2. The diffuser had a slight area contraction immediately upstream of the compressor face station due to the presence of the simulated compressor hub.

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Total-pressure recovery was determined from an area-weighted average of 30 total-pressure tubes at fuselage station 40.50 as shown in detail A of figure 1. The mass-flow ratio, which was regulated by a remotely controlled plug at the duct exit (figs. 1(a) and (b)), was computed from the average Mach number determined from total- and static-pressure measurements at station 40.50.

The mass-flow ratio through the boundary-layer bleed duct was determined from area-weighted average total-pressure recovery and average Mach number which were measured by the static- and total-pressure tubes shown in detail B of figure 1. Three positions of the flap valve were used to control the flow rates through the boundary-layer-bleed slot. These positions which are noted as F_1 , F_2 , and F_3 represent flap valve opening areas equal to 13, 26, and 52 percent of the inlet area, respectively.

The model was tested with the center line of the side inlet (fig. 1(b)) at $+1^\circ$ angle of attack relative to the tunnel airstream.

Distortions which were determined from local total pressures measured at the compressor face rake are defined as

$$\left(\frac{P_{t_{\max}} - P_{t_{\min}}}{P_{t_{\text{av}}}} \right)_2$$

A strain-gage pressure pickup cell was installed on the inboard wall of the duct at fuselage station 27.42. Indications of pressure fluctuations from this cell were used to determine the minimum stable mass-flow ratio. Duct-flow buzz was observed on the schlieren screen when pressure fluctuations exceeded $0.05 P_{t_\infty}$.

All pressure ratios, which are presented for the port duct only, were determined within an accuracy of ± 0.005 .

RESULTS AND DISCUSSION

The design of a boundary-layer-bleed throat slot can have pronounced effects on the internal performance of an external compression inlet. In this test a comparison has been made of the effects on inlet performance of varying the size of the boundary-layer-bleed slot and the mass-flow rate through the slot. The large spillages due to the off design operation of this inlet are believed to have negligible influence on the internal performance. The effectiveness of the boundary-layer-bleed systems is compared for two free-stream Mach numbers, 2.3 and 2.0.

Varying the Slot Width - Bleed Control Valve Position Constant

To approximate a constant boundary-layer-bleed mass-flow rate while the throat slot size was varied, the bleed mass-flow control valve was maintained at a constant opening. The results of testing under this condition have been presented in figure 3.

Increasing the width of the boundary-layer-bleed slot adversely affected the maximum pressure recovery, critical mass-flow ratio, and distortion at $M_\infty = 2.3$ as noted in figure 3(a).

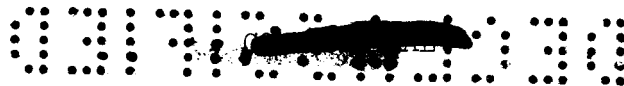
Although the increase in slot width resulted in larger bleed mass-flow rates, the maximum pressure recovery decreased by 0.035.¹

The reduction in critical mass-flow ratio that accompanied the increase in bleed slot width would be detrimental, since for a given engine air-flow requirement, it would require a larger capture area and consequently would increase the external drag.

These adverse effects of increased bleed slot width on inlet performance are more pronounced at $M_\infty = 2.3$ than at $M_\infty = 2.0$, as seen in figures 3(a) and (b).

Figures 3(c) and (d) present the effects of increasing slot width on inlet performance when a larger bleed control valve opening area, F_2 , was used. It will be noted that the results in figure 3(c) do not follow the trend of figures 3(a), (b), and (d); namely, when the slot width is increased, the maximum pressure recovery is decreased. This decrease is believed to result from choking of the $a_s/a_1 = 0.26$ slot for all control valve settings greater than F_1 . This choked condition is evident when the bleed mass-flow ratios for the $a_s/a_1 = 0.26$ slot are compared in figures 3(a) and (c). Increasing the control valve opening area from F_1 to F_2 did not significantly change the bleed mass-flow ratio or the pressure recovery.

¹Although it might be thought that the decrease in maximum pressure recovery could have been caused by reversed flow through the second ramp porous area from the common exit bleed duct, it is unlikely that this occurred since the theoretical static pressure on the second ramp was always greater than the static pressure at the bleed duct rake by a factor of two or more.



Varying Bleed Mass-Flow Rates - Throat Slot Size Constant

The effect on inlet performance of varying the bleed mass-flow rate while maintaining a constant throat slot size is presented in figure 4. In general, an increase in bleed flow rate for a constant throat slot size resulted in an increase in inlet maximum pressure recovery and an accompanying decrease in distortion. This effect was most pronounced for the inlet with the $a_s/a_i = 0.52$ slot at $M_\infty = 2.3$, as shown in figure 4(a). Here the maximum pressure recovery increased by 0.03 while distortion decreased approximately by 0.03 with approximately a 54-percent increase in bleed mass-flow ratio. A further increase in control valve opening area to 100 percent of a_i , data for which have not been presented, did not increase the bleed mass-flow rate or affect the inlet performance.

The effects on inlet performance of varying bleed mass-flow rates are also presented for the $a_s/a_i = 0.26$ slot in figures 4(c) and (d). The bleed flow rates of figure 4(c) do not vary with a change in bleed control valve area because of the choked throat slot condition previously described. As in the case of varying the throat slot size, the effects of varying bleed mass-flow rates on inlet performance were more pronounced at $M_\infty = 2.3$ than at $M_\infty = 2.0$.

Boundary-Layer Bleed Slot Size At Optimum Bleed Mass Flow

The results presented so far have shown that the effects of varying throat slot size and bleed flow rates on inlet performance are different. While a reduction in slot size improved the inlet pressure recovery and lessened distortion, so did an increase in bleed flow rate. Therefore, it is necessary to compare the performance of the inlets with the different slot sizes at the best obtainable bleed flow rates as presented in figure 5. In general, there were minor variations in inlet pressure recovery and distortion but significant changes occurred in critical mass-flow ratio because of the higher bleed flow rates of the larger sized slots. The inlet with the $a_s/a_i = 0.13$ slot had a 0.065 higher critical mass-flow ratio than the inlet with the $a_s/a_i = 0.52$ slot. This variation was approximately equal to the difference in bleed mass-flow ratios when two points of equal pressure recovery are compared. At $M_\infty = 2.3$, the inlet with the $a_s/a_i = 0.26$ slot had a lower maximum pressure recovery and higher distortion values than the inlet with either of the other slots.

To determine the advantage directly attributable to the boundary-layer-bleed slot, the inlet was tested with the slot faired over and the porous second ramp with leading-edge slot operating as the sole means of



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boundary-layer control. As seen in figure 5(a), the addition of the throat slot increased maximum pressure recovery by 0.025 with an increase in bleed mass-flow ratio of 0.02 to 0.09 and a concomitant decrease in distortion.

The variations in slot size had only a minor influence on the compressor face pressure distributions, as shown in figure 6 at $M_\infty = 2.3$ and 2.0. The pressure distributions have been presented for three representative mass-flow regions which are (1) critical mass-flow ratio, (2) a normal operating condition of approximately 0.95 critical mass-flow ratio, and (3) the minimum stable mass-flow ratio condition.

A Assuming that with the 13 and 52 percent of a_1 slots the diffuser
3 losses were equal, the advantages that can be gained by using the smaller
4 slot size include (1) a smaller bleed mass-flow rate resulting in a
5 reduction in the volume and weight of the bleed flow conduit structure,
and (2) a higher critical mass-flow ratio resulting in a smaller capture
area and consequently a decrease in external drag for inlet-engine
matching conditions.

CONCLUDING REMARKS

An investigation was conducted to determine the effects on internal performance of varying the width of and mass-flow rate through the boundary-layer-control bleed slot located at the throat of an external compression inlet immediately ahead of a rapid turn. Test results showed that an increase in throat slot area required an increase in bleed flow rate to maintain maximum pressure recovery and low distortion values for the inlet.

The performance of the inlet with the boundary-layer-control throat slot area equal to 13 percent of the inlet area is comparable in pressure recovery and distortion to that of the inlet with a slot area four times as large with the added advantages of (1) a smaller bleed mass-flow rate which would result in a reduction in bleed ducting volume and weight, and (2) a higher critical mass-flow ratio which would permit a reduction in capture area and consequently external drag for inlet-engine matching conditions.

Ames Research Center

National Aeronautics and Space Administration

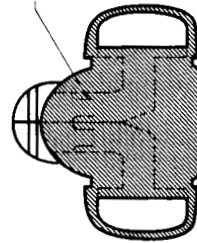
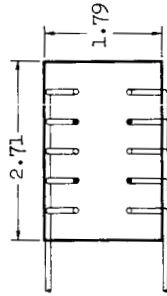
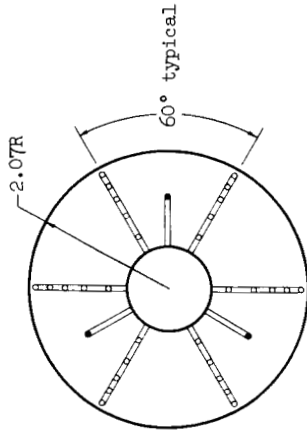
Moffett Field, Calif., Jan. 6, 1961

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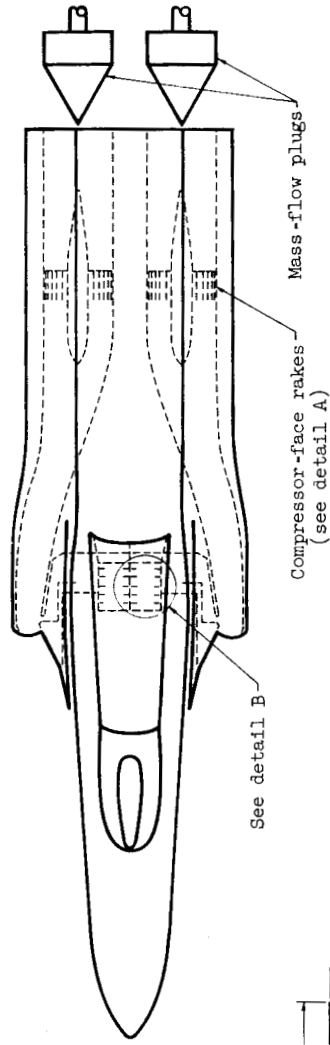
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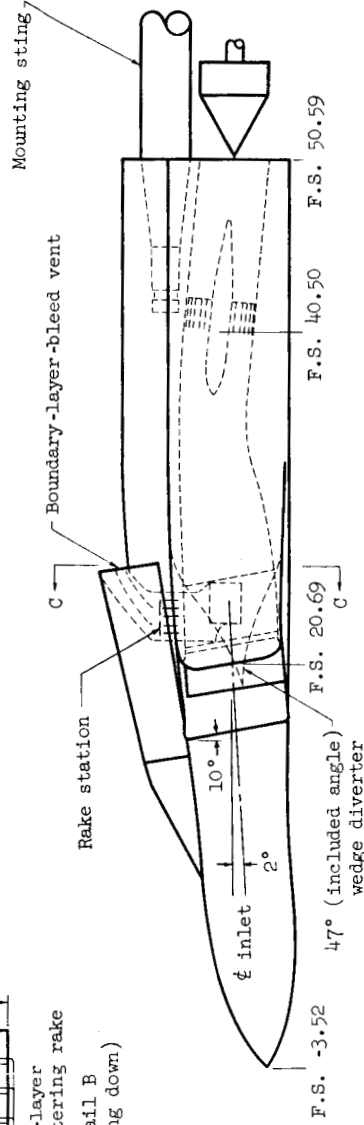
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All dimensions in inches unless otherwise noted.

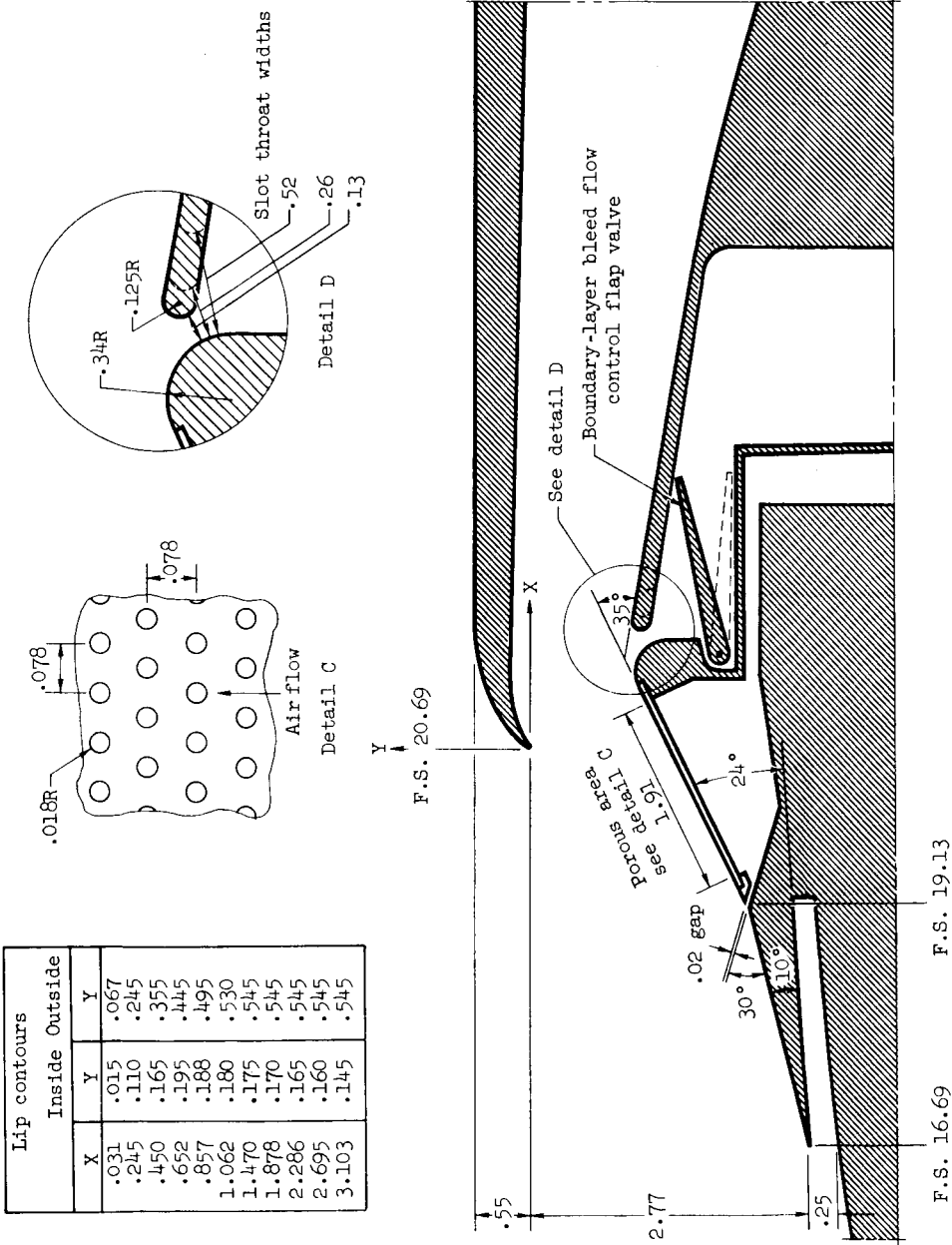


(a) Plan view of model.



(b) Side view of model.

Figure 1.- Drawing of model and inlets.



(c) Section at center line of inlet.

Figure 1.- Concluded.

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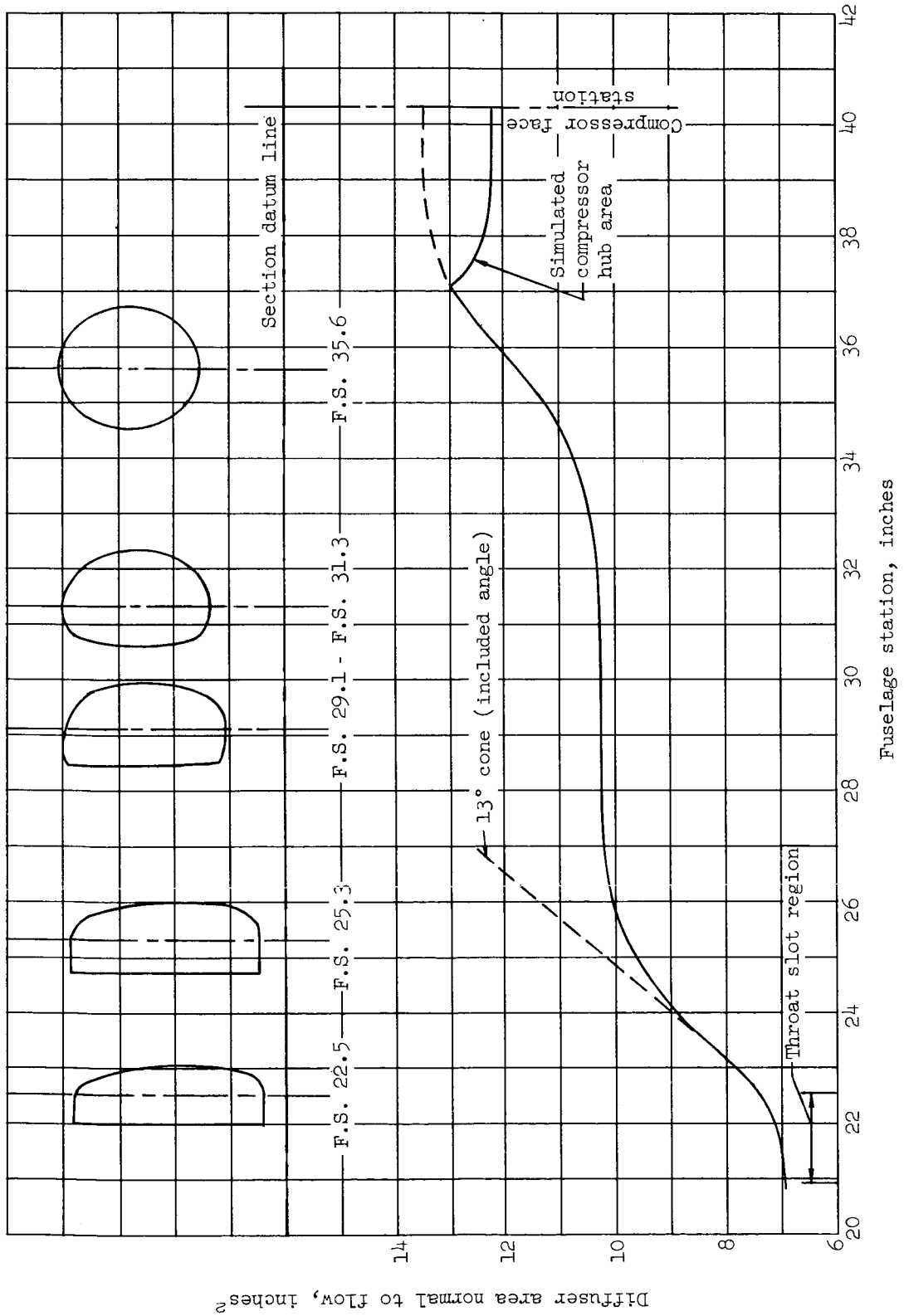


Figure 2.- Diffuser area distribution.

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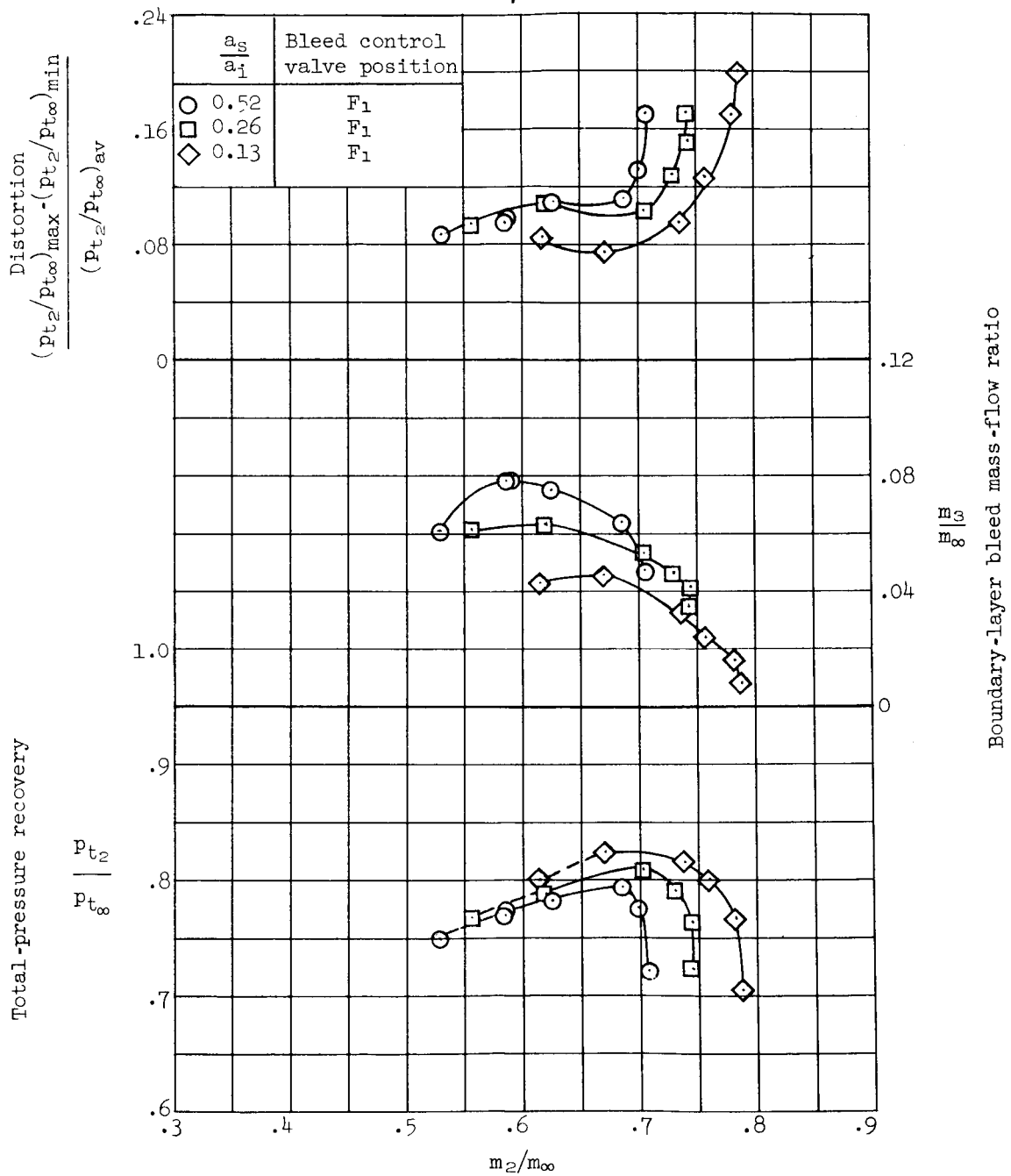
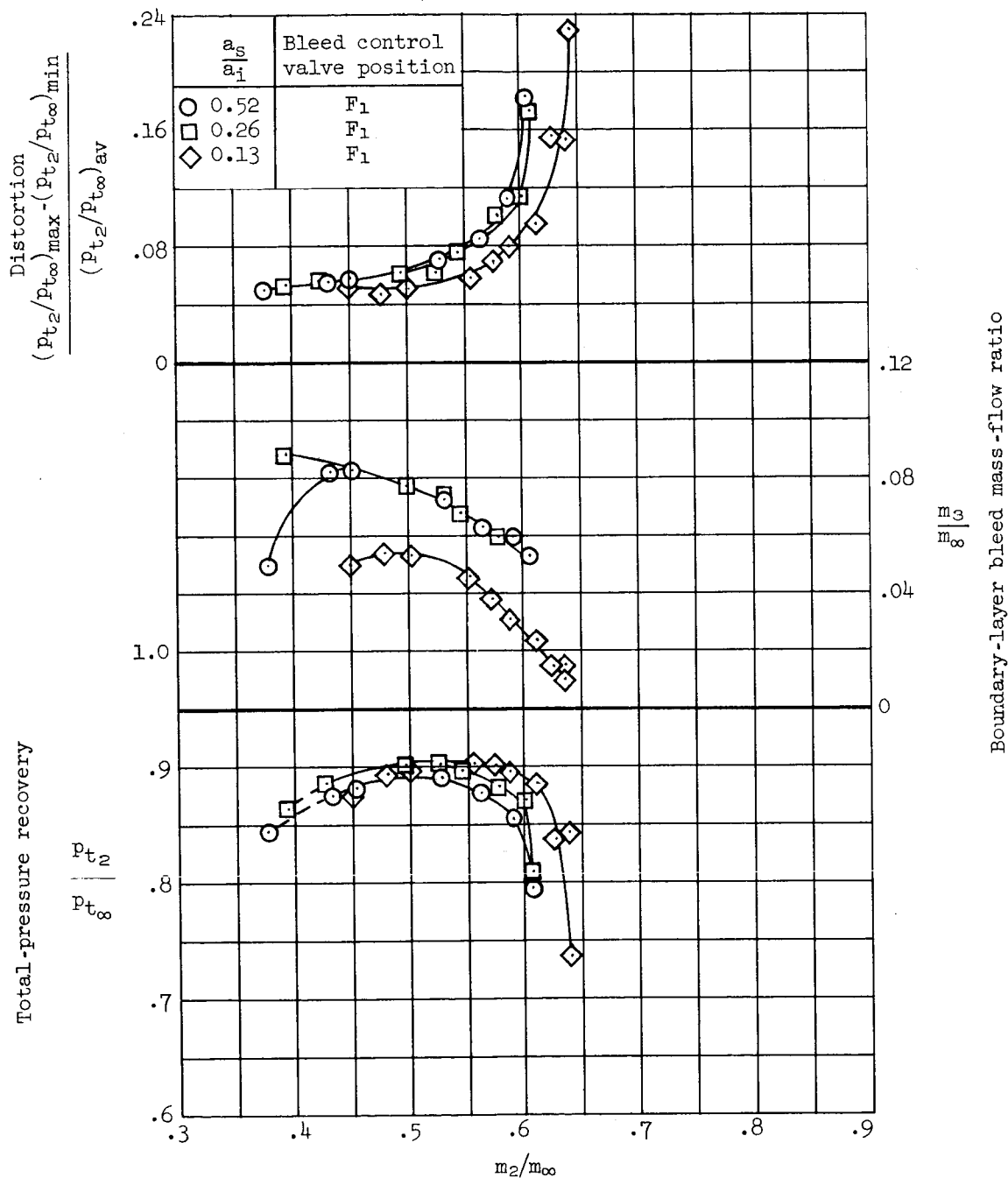
(a) $M_\infty = 2.3$

Figure 3.- Effect of inlet throat slot size; position of bleed control valve constant.



(b) $M_\infty = 2.0$

Figure 3.- Continued.

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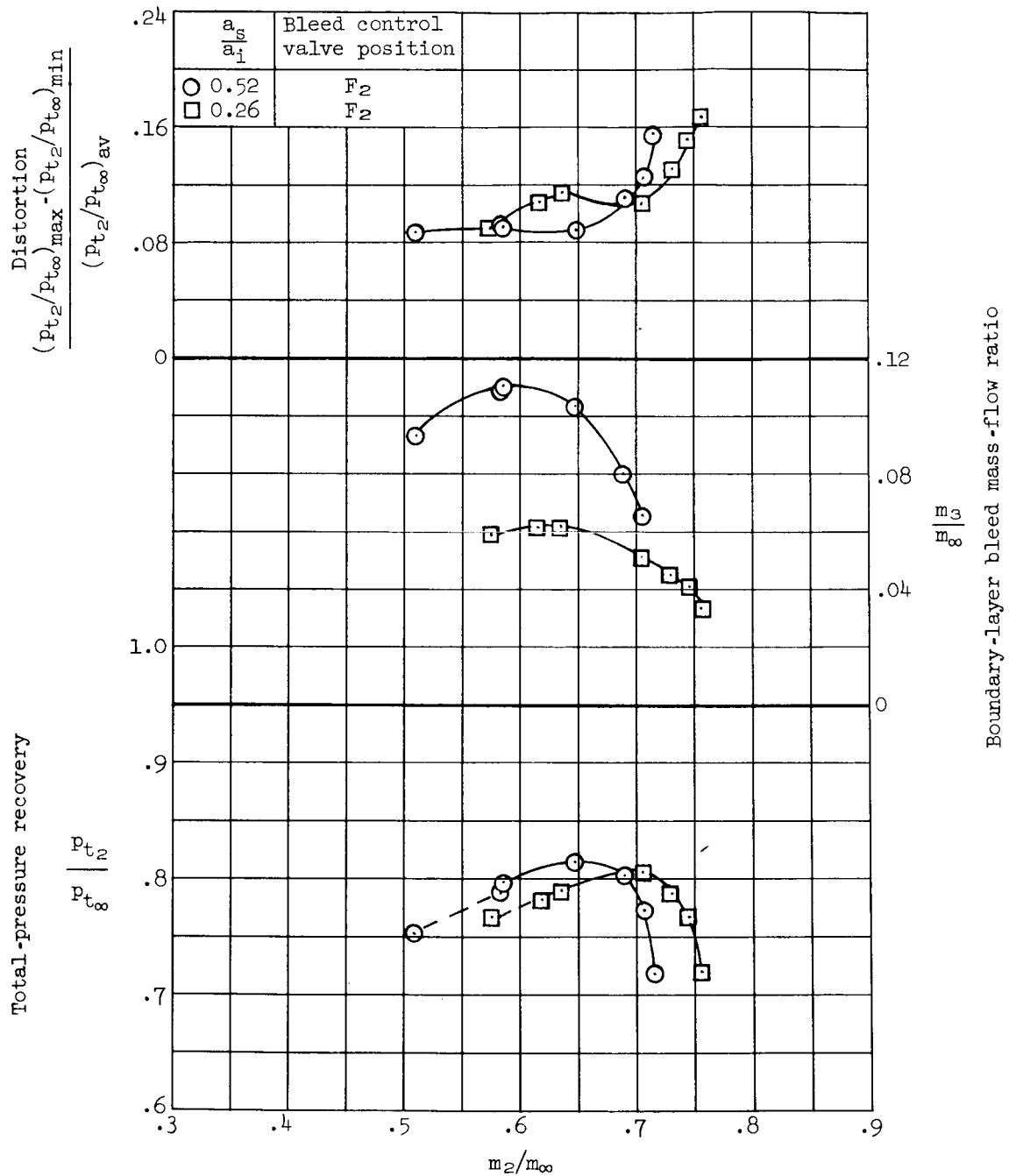
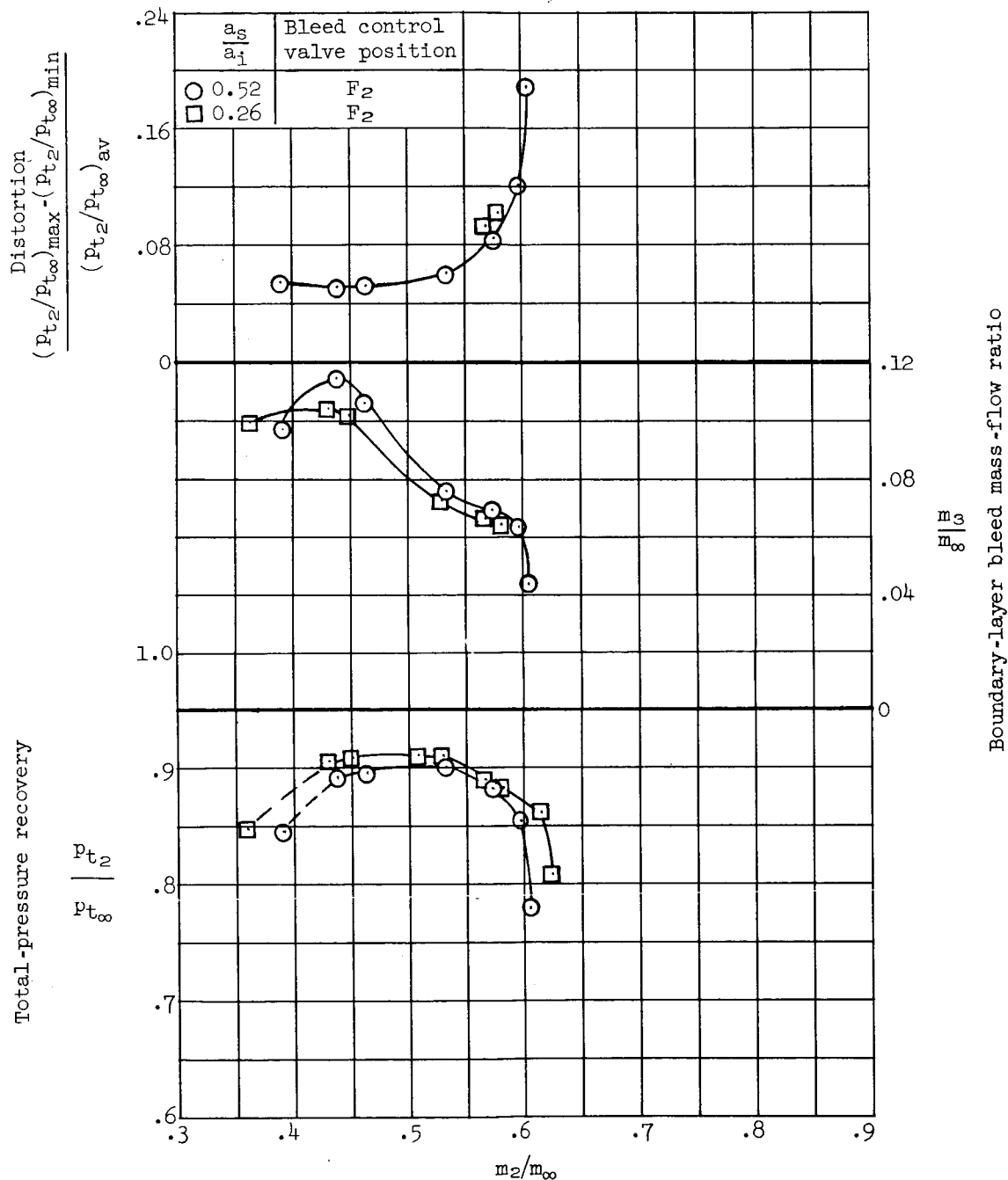
(c) $M_\infty = 2.3$

Figure 3.- Continued.

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(d) $M_\infty = 2.0$

Figure 3.- Concluded.

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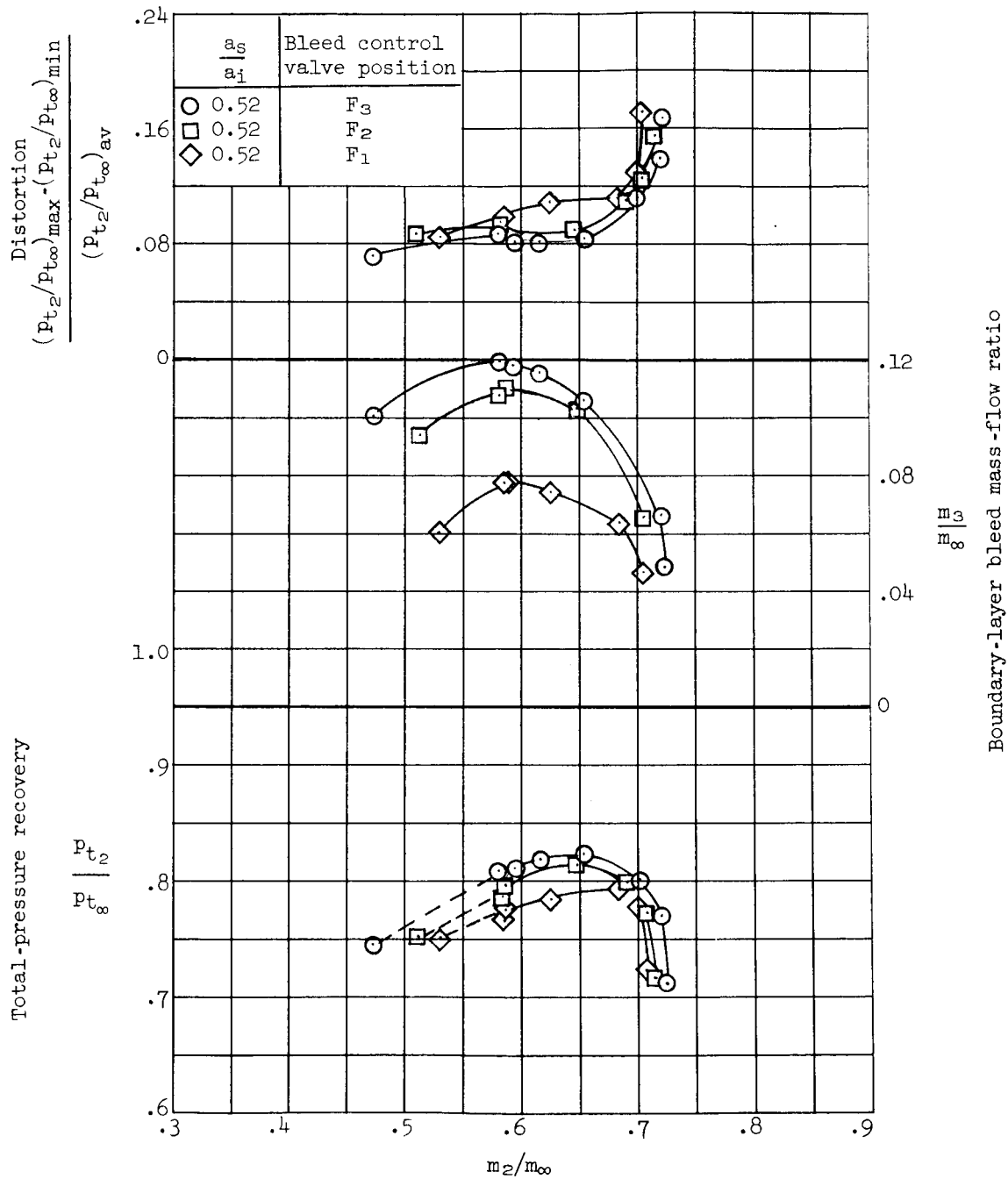
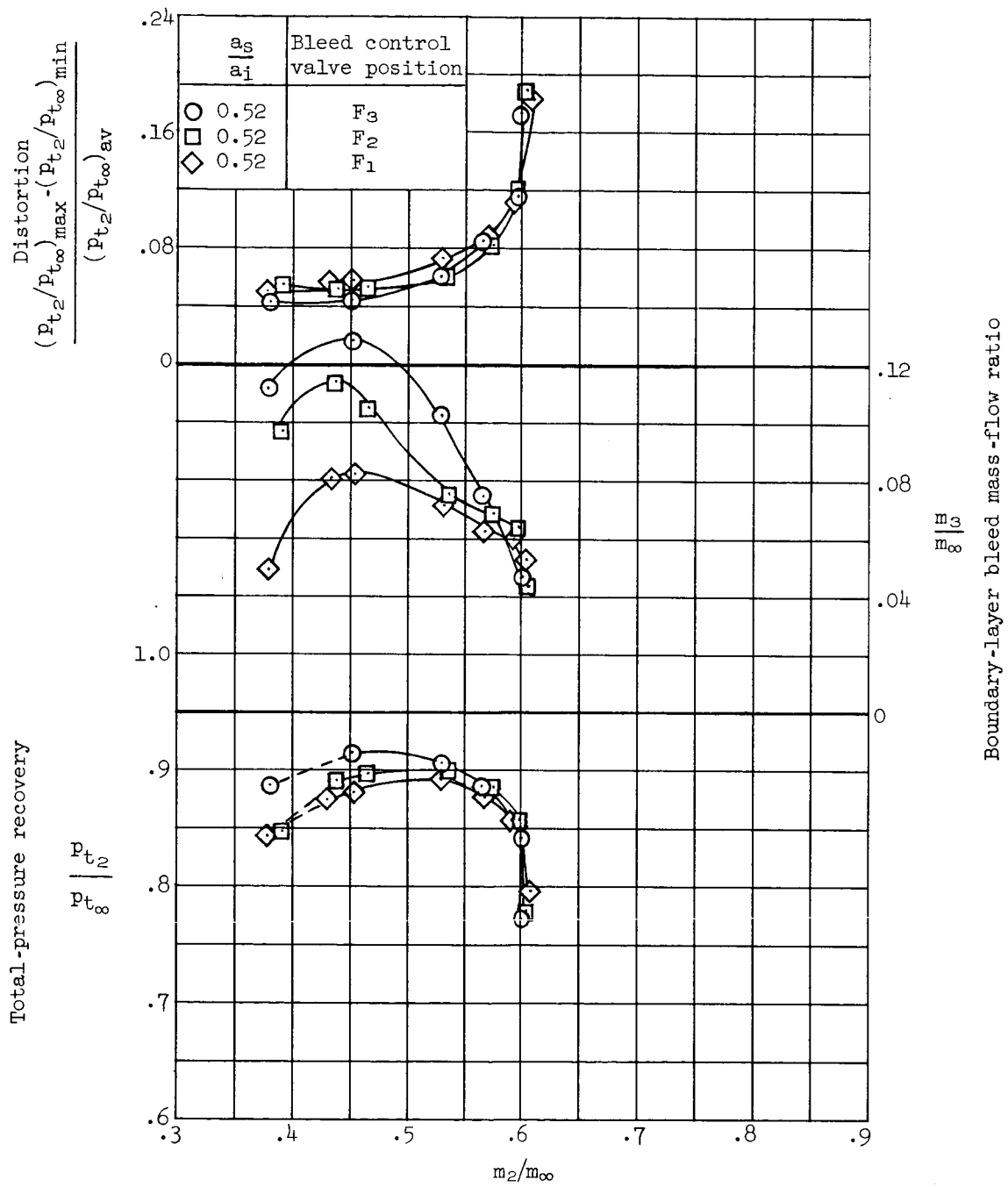
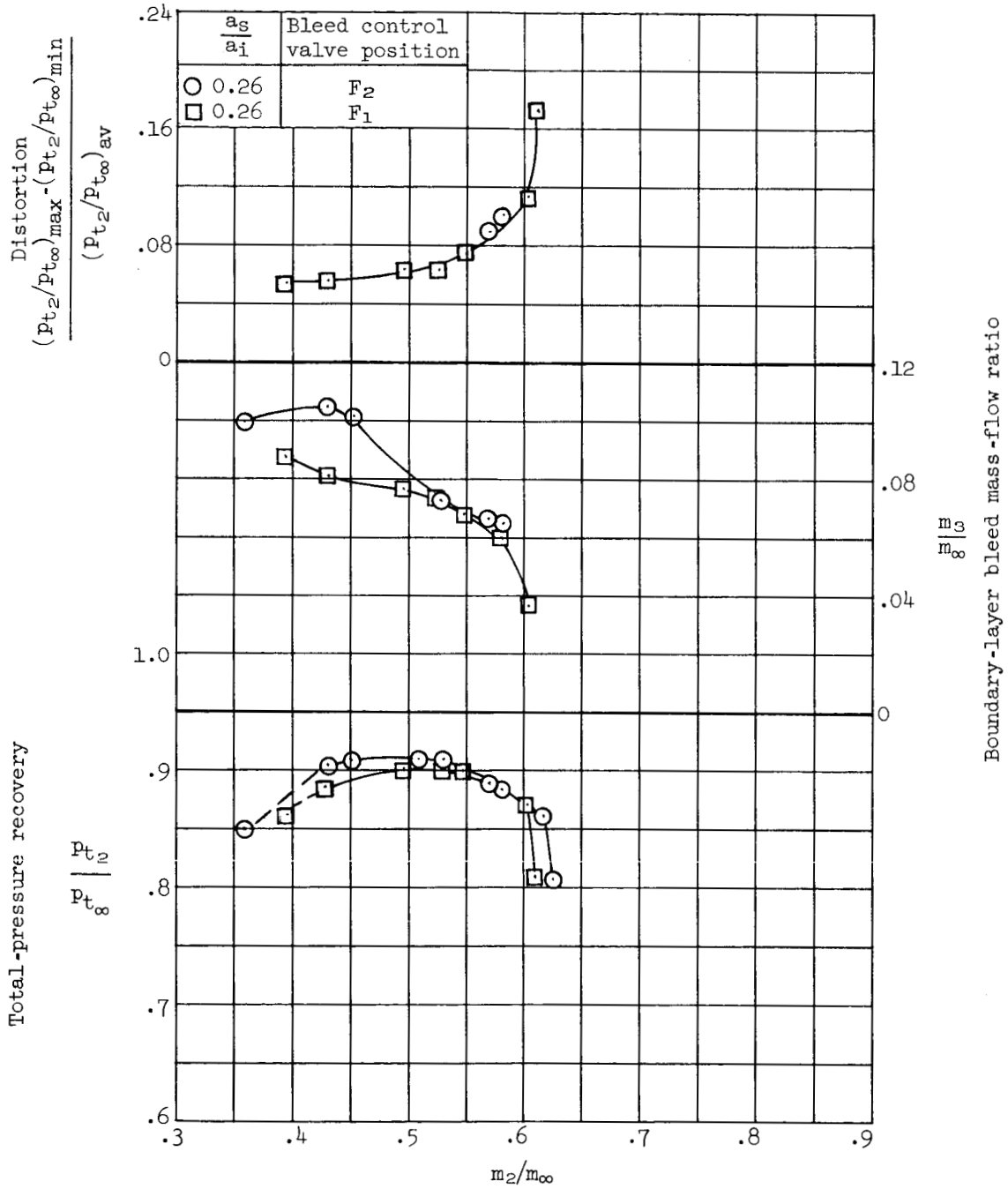
(a) $M_\infty = 2.3$

Figure 4.- Effect of bleed mass-flow rate.



(b) $M_\infty = 2.0$

Figure 4.- Continued.



(d) $M_\infty = 2.0$

Figure 4.- Concluded.

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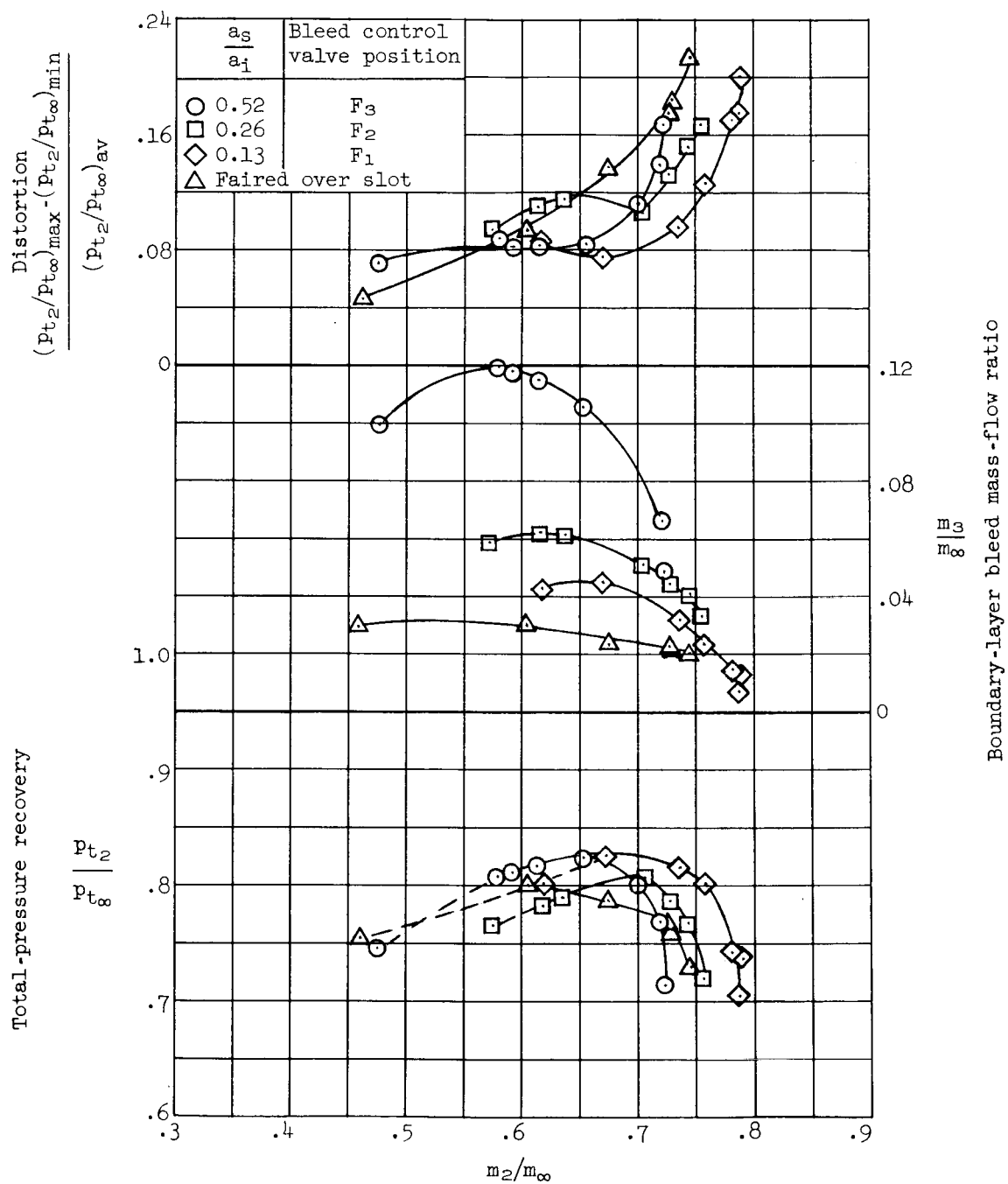
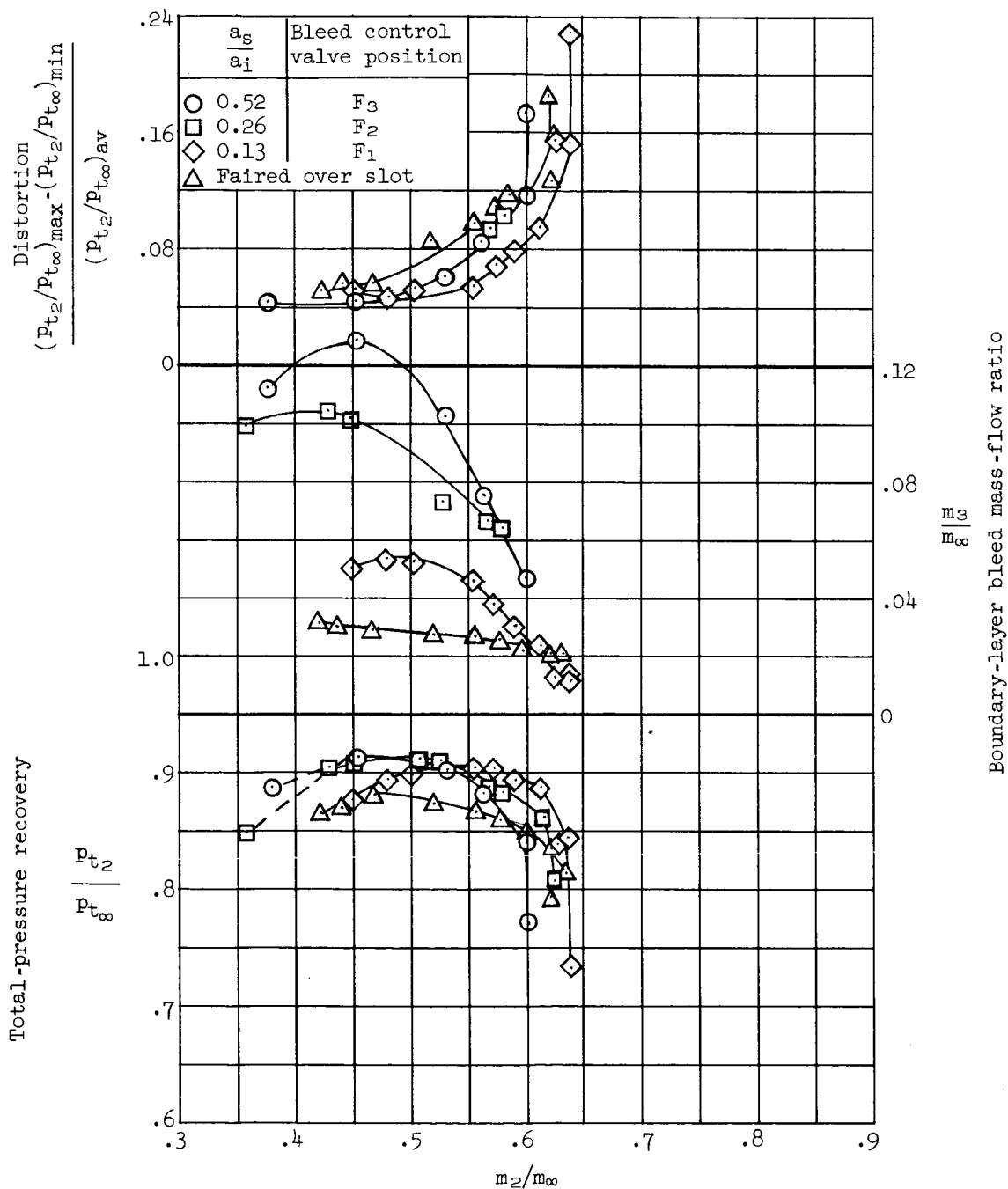
(a) $M_\infty = 2.3$

Figure 5.- Effect of inlet throat slot size with optimum bleed mass flow.



(b) $M_{\infty} = 2.0$

Figure 5.- Concluded.

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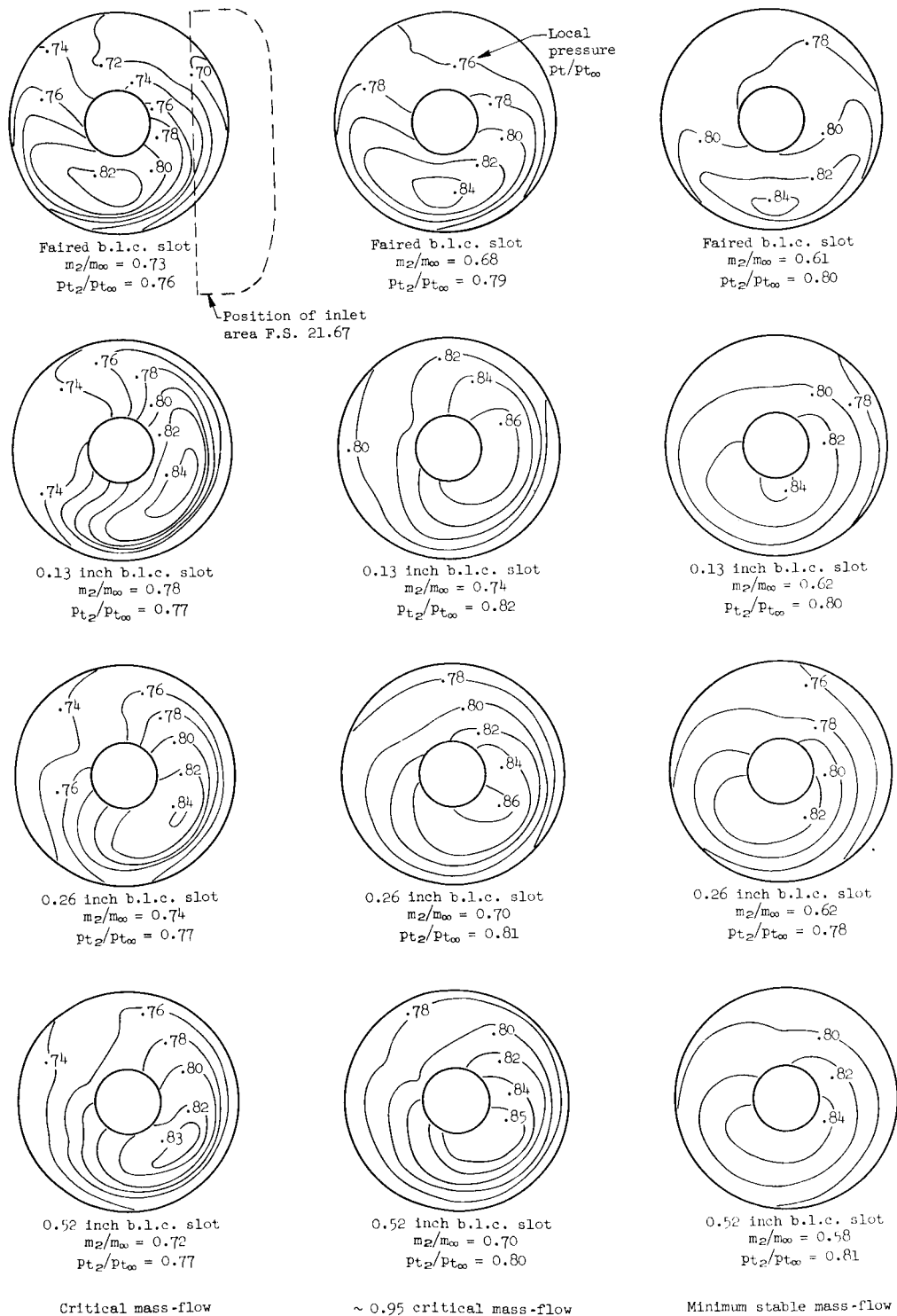
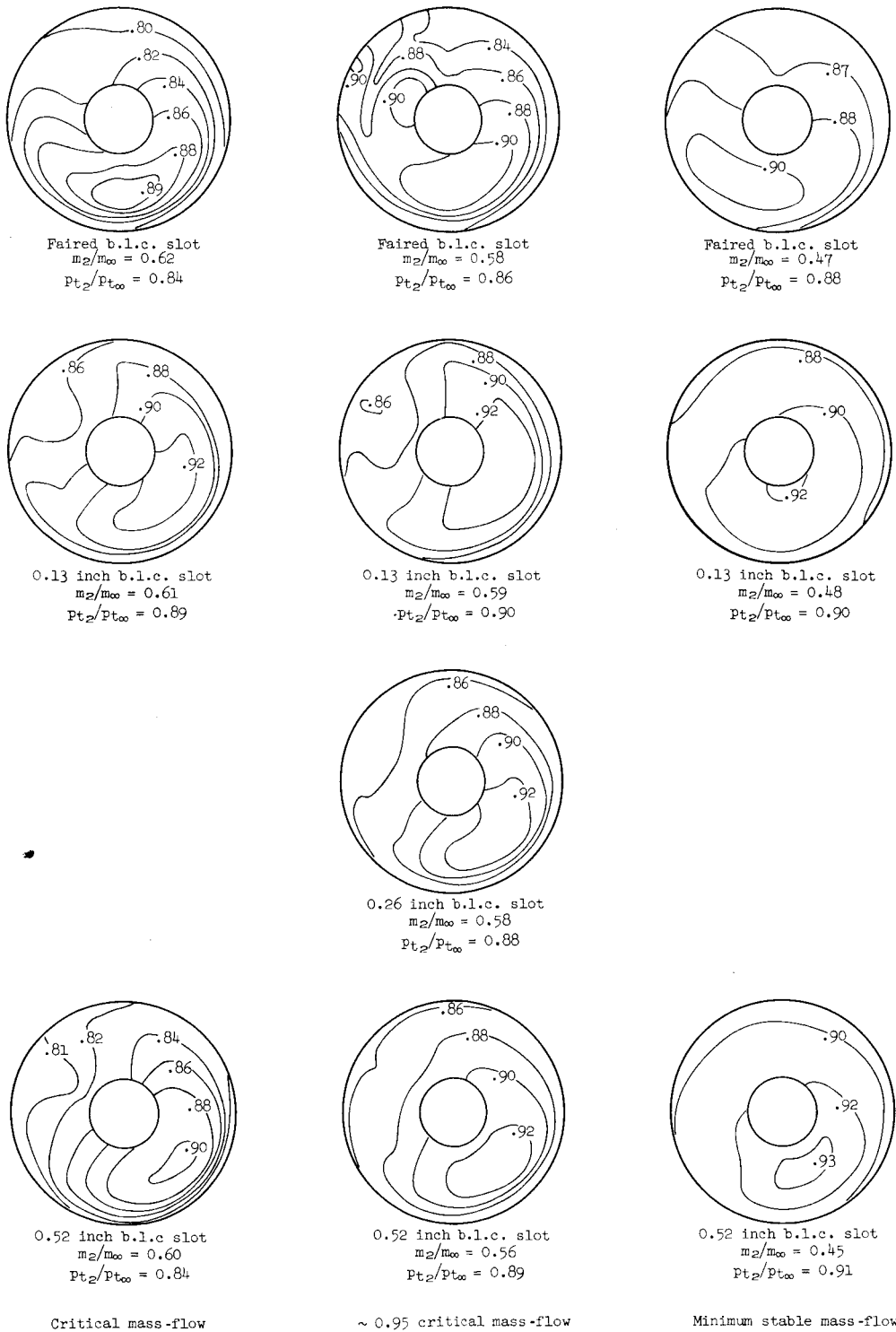
(a) $M_{\infty} = 2.3$

Figure 6.- Compressor face pressure distributions.

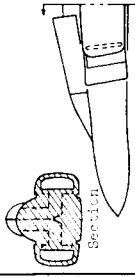
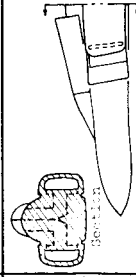
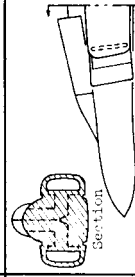



(b) $M_{\infty} = 2.0$

Figure 6.- Concluded.

NOTES: (1) Reynolds number is based on the diameter of a circle with the same area as that of the capture area of the inlet.

(2) The symbol * denotes the occurrence of buzz.

Report and facility	Description			Test parameters					Test data			Performance		Remarks	
	Configuration	Number of oblique shocks	Type of boundary-layer control	Free-stream Mach number	Reynolds number $\times 10^{-6}$	Angle of attack, deg	Angle of yaw, deg	Inlet-flow profile	Discharge-flow profile	Flow picture	Maximum total-pressure recovery	Mass-flow ratio ¹			
CONF. Ares 9-by 7-ft. Unitary Plan Wind Tunnel		Section	2	2	Porous + Small slot	2.3	.85 to .93	3.0	0		✓		0.800	0.606	Faired over slot Slot area = .13 inlet area
			2	2	Porous + Large slot	2.3	.85 to .93	3.0	0		✓		.827	.672	Slot area = .52 inlet area
			2	2	Porous + Large slot	2.3	.85 to .93	3.0	0		✓		.825	.653	Based on inlet capture area
CONF. Ares 9-by 7-ft. Unitary Plan Wind Tunnel		Section	2	2	Porous + Small slot	2.3	.85 to .93	3.0	0		✓		0.800	0.606	Faired over slot Slot area = .13 inlet area
			2	2	Porous + Large slot	2.3	.85 to .93	3.0	0		✓		.827	.672	Slot area = .52 inlet area
			2	2	Porous + Large slot	2.3	.85 to .93	3.0	0		✓		.825	.653	Based on inlet capture area
CONF. Ares 9-by 7-ft. Unitary Plan Wind Tunnel		Section	2	2	Porous + Small slot	2.3	.85 to .93	3.0	0		✓		0.800	0.606	Faired over slot Slot area = .13 inlet area
			2	2	Porous + Large slot	2.3	.85 to .93	3.0	0		✓		.827	.672	Slot area = .52 inlet area
			2	2	Porous + Large slot	2.3	.85 to .93	3.0	0		✓		.825	.653	Based on inlet capture area
CONF. Ares 9-by 7-ft. Unitary Plan Wind Tunnel		Section	2	2	Porous + Small slot	2.3	.85 to .93	3.0	0		✓		0.800	0.606	Faired over slot Slot area = .13 inlet area
			2	2	Porous + Large slot	2.3	.85 to .93	3.0	0		✓		.827	.672	Slot area = .52 inlet area
			2	2	Porous + Large slot	2.3	.85 to .93	3.0	0		✓		.825	.653	Based on inlet capture area

Bibliography

These strips are provided for the convenience of the reader and can be removed from this report to compile a bibliography of NASA inlet reports. This page is being added only to inlet reports and is on a trial basis.